

VU Research Portal

Interception of moving objects while walking in children with Spastic Hemiparetic Cerebral Palsy

Ricken, A.X.C.; Savelsbergh, G.J.P.; Bennett, S.J.

published in

Disability and Rehabilitation
2007

DOI (link to publisher)

[10.1080/09638280600947922](https://doi.org/10.1080/09638280600947922)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Ricken, A. X. C., Savelsbergh, G. J. P., & Bennett, S. J. (2007). Interception of moving objects while walking in children with Spastic Hemiparetic Cerebral Palsy. *Disability and Rehabilitation*, 29(1), 69-77.
<https://doi.org/10.1080/09638280600947922>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Interception of moving objects while walking in children with Spastic Hemiparetic Cerebral Palsy

ANNIECK X. C. RICKEN^{1,4}, G. J. P. SAVELSBERGH^{1,2} & S. J. BENNETT³

¹Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Free University of Amsterdam, The Netherlands, ²Institute for Biophysical and Clinical Research into Human Movement, Manchester Metropolitan University, UK, ³Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, UK, and ⁴Rehabilitation Centre Amsterdam, The Netherlands

Accepted June 2006

Abstract

Purpose. The purpose of the study was to examine the coordination of reaching and walking behaviour when children with Spastic Hemiparetic Cerebral Palsy (SHCP) intercept an approaching and hence externally-timed object.

Method. Using either the impaired or non-impaired arm, children intercepted a ball approaching from a fixed distance with one of three velocities. Each participant's initial starting position was scaled to their maximum walking velocity determined prior to testing; for the medium ball velocity, participants would arrive at the point of interception at the correct time if they walked with their maximum velocity.

Results. Children with SHCP adapted their reaching and walking behaviour to the different ball approach velocities. These adaptations were exhibited when using the impaired and non-impaired arm, and resulted in similar outcome performance irrespective of which arm was used. Still, children with SHCP found it necessary to increase trunk movement to compensate for the decreased elbow excursion and a decreased peak velocity of the impaired arm.

Conclusion. Children with SHCP exhibited specific adaptations to their altered movement capabilities when performing a behaviourally-realistic task. The provision of an external timing constraint appeared to facilitate both reaching and walking movements and hence could represent a useful technique in rehabilitation.

Keywords: Spastic hemiparetic cerebral palsy, children interception, moving objects, walking, reaching, coordination, external timing, constraints

Introduction

The question of how children with Spastic Hemiparetic Cerebral Palsy (SHCP) coordinate their arm and trunk movements during interceptive actions has generated much interest. It has been found that children with SHCP show differences in the coordination of their impaired arm compared to their non-impaired arm even when the movements are performed bimanually rather than unimanually [1]. The differences in the reach movements of the non-impaired arm compared to the impaired arm are characterized by some of the typical movement limitations imposed by SHCP. For example, it is often reported that there is less elbow excursion accompanied with more trunk involvement, as well as

lower velocity movements when using the impaired arm compared to the non-impaired arm [2].

An important characteristic of coordinated movements involved in interceptive actions such as catching, prehension, and hitting and striking, is that they often require precise adjustment and adaptation to the changing circumstances of the environment. In this respect, the resulting coordinated movement is dependent on the evolving relationship between the actor and the objects in the environment. When this relationship is altered, for example when the approaching balls have different velocities, it is often necessary to modify ones movements in order to maintain successful performance [3,4]. But, what happens when the actor has impaired movement capabilities as a result of SHCP?

Given the necessary tight coupling between perception and action, ideally the response to different environmental demands should take account of the individual's own movement capabilities [5,6]. Indeed, work on adults with SHCP has shown that although they move slower and exhibit more trunk involvement when intercepting objects with the impaired arm [7], these changes in movement represent an adaptive mechanism to improve reaching accuracy rather than simply being the result of the impairment [8,9]. To date, however, there has been limited empirical work on how children with SHCP adapt to their altered movement capabilities. This is an important omission because this knowledge may inform practice in rehabilitation. One particularly relevant study was reported by [10], who showed that children with SHCP hitting a ball approaching on a track started the movement earlier with the impaired arm compared to the non-impaired arm. The authors concluded that the SHCP children used an adaptive strategy that compensated for the fact that the impaired arm could not be moved as fast as the non-impaired arm. In other words, this adaptive strategy of "creating extra time" took account of the SHCP children's own movement capabilities.

Recently, there has been some work that has examined how children with SHCP perform more behaviourally-realistic tasks. It has been shown that when walking to intercept a stationary or moving ball, the forward motion of the trunk due to walking is coordinated with the movement of the arm [11]. A related study also showed that the time spent decelerating the arm towards the object was increased to compensate for the altered arm movement possibilities due to the impairment [2]. Interestingly, the SHCP children in the latter study were also able to increase their elbow excursion and wrist peak velocity when reaching with the impaired (and non-impaired) arm when the movements were externally timed (i.e., moving ball) compared to internally timed (i.e., stationary ball). In other words, when intercepting a moving ball SHCP children were able to adapt the movement of their impaired arm to the more severe temporal constraints, and in part overcome the rate-limiting factor of spasticity. The facilitation of performance in externally-timed tasks is similar to the work by [12], who found that hemiparetic stroke patients improved movement performance, as indexed by an increase in range of motion, when hitting a moving compared to a stationary ball.

Following from the preliminary evidence of a difference between SHCP children's interceptive movements performed in the context of internal compared to external timing constraints, it remains to be examined in more detail how walking and reaching movements are coordinated when performing interceptive actions that impose different levels of

external timing constraint. To this end, the present study examined SHCP children's walking and reaching movements when intercepting a ball that approached from a fixed distance (scaled to each child's walking capabilities) with different velocities.

Methods

Participants

Ten children with mild/moderate SHCP (mean age 8.6 year, SD = 1.8 year) participated in the experiment. The classification of severity of SHCP was based on discussion with the children's parents and/or physiotherapist regarding the degree of movement impairment (parents confirmed these observations were consistent with medical records). Both the children and their parents signed informed consent forms. The study was approved by the Regional Committee for Medical Research Ethics, Manchester, UK. Participants were UK residents and volunteered after parents were informed by an advertisement in the newsletter of "Hemihelp". Inclusion criteria were: congenital spastic hemiparetic cerebral palsy, able to stand and walk independently, able to use the impaired arm, aged between 5–11 years old. Exclusion criteria were: ataxia, athetose, wheelchair dependency, and mental retardation. The participant information on the inclusion criteria was obtained when parents informed the research team about the medical records (that came from the hospital or rehabilitation centre) of each child (see Table I). For five of the participants cerebral palsy was congenital, arising as a consequence of lack of oxygen at birth or by an infection. Three participants were part of twins and cerebral palsy was caused by a premature birth, and for two participants the cause was unknown. Three of the children wore a foot orthosis on the leg of the impaired side of the body, but no orthoses were worn on the arms.

Procedure and design

Participants were instructed to reach and grasp an approaching ball with either their impaired or non-impaired arm while walking. Table height was adjusted to the participant's body height such that it was level with the end of the thumb when the arm was held vertically beside the table. The ball rolled down an open tube of 2.50 m length and travelled on a path that brought it to the general vicinity of a marker located on the table (a blue circle of 10 cm diameter) (see Figure 1). By modifying the angle of the open tube, the moving ball could be made to approach the participant with three different velocities: V1 (0.75 m/s), V2 (1.05 m/s) and V3

For each participant an individual starting position was calculated, which was scaled to the individual's maximum average walking velocity. The maximum average walking velocity was calculated for each child by instructing them to walk as fast as possible, 5 times over a distance of 3 m. The average walking velocity varied between 0.98 and 1.52 m/s across participants. Using these values and the time to arrival specified by the medium ball approach velocity (V_2), the distance between the starting position and point of interception ranged from 1.03–1.59 m. These values represent the theoretical distance from which participants could intercept a ball with the medium approach velocity if they walked with their maximum velocity. To become familiar with the task, participants performed three practice trials. When

Apparatus

Dependent measures

Although the interceptive action performed in the present study consisted of both a reach and grasp phase only the former was analysed. A program was developed to identify key events in the displacement

Participant	Diagnosis	Aetiology	Age (years)
1	Right spastic hemiparesis	CP: lack of O ₂	7
2	Left spastic hemiparesis	CP: lack of O ₂	10
3	Right spastic hemiparesis	CP: premature	5
4	Right spastic hemiparesis	CP: premature	9
5	Right spastic hemiparesis	Unknown	9
6	Left spastic hemiparesis	CP: lack of O ₂	7
7	Right spastic hemiparesis	CP: lack of O ₂	8
8	Right spastic hemiparesis	CP: lack of O ₂	11
9	Left spastic hemiparesis	CP: premature	9
10	Left spastic hemiparesis	Unknown	11

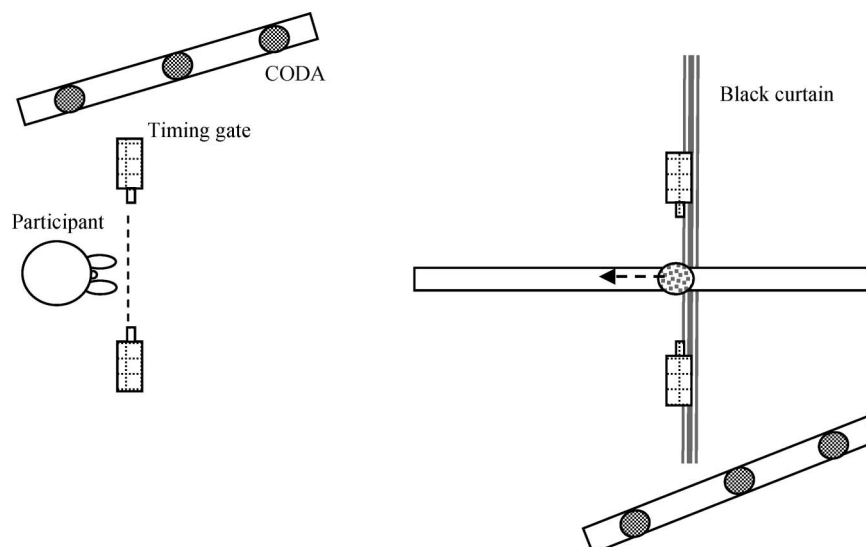


Figure 1. Schematic top view of the experimental set-up.

and velocity profiles of linear and angular data of the upper limbs. Based on previous research on reaching in children without SHCP [11] and children with SHCP [1,2,13], the following linear kinematic data of the wrist movements were extracted: Initiation time of the reach, movement time (MT), wrist peak velocity (PVX and PVY), deceleration time of the wrist (TAPVX and TAPVY) and wrist velocity prior to contact (VPTC). Wrist peak velocity, wrist velocity prior to contact and deceleration time of the wrist were calculated relative to a world-centred and a body-centred frame of reference. The world-centred perspective describes hand movements in x, y, and z-co-ordinates relative to the workspace of the task, whereas for the body-centred perspective hand movements are calculated relative to a dynamic frame of reference (i.e., the trunk). The latter frame of reference describes hand movements that are independent of angular motion of the trunk caused by flexion and rotation, and linear motion of the trunk resulting from walking. To determine the reach phase of the interceptive action, the moment of initiation was defined by first searching backwards from the moment of contact until the moment wrist velocity (in vertical direction) reached a zero-crossing, and then from this point searching for the moment wrist velocity reached a zero-crossing as it changed from a positive to negative value. The moment of contact was identified by first finding the moment at which the distance between the horizontal position of the wrist and ball became less than 15 cm, then searching backwards for the moment wrist velocity (in vertical direction) increased beyond zero, and finally searching backwards again until wrist velocity was less than -0.05 m/s for 5 consecutive frames.

In addition to linear kinematic data of the reach, the following angular kinematic variables were extracted: Trunk rotation, trunk flexion, trunk lateral flexion, shoulder flexion, shoulder elevation, and elbow excursion. The angular data was only calculated in a world-centred perspective. Trunk contribution to the reach response was quantified by calculating angular excursion, where excursion is the sum of the angular change over time. These variables were calculated from the angle formed between the markers placed on the sternum, shoulder and pelvis in a sagittal, transverse and frontal plane. Trunk rotation was defined as the movement of the trunk in the transverse plane around the y-axis, trunk flexion was defined as the movement in the sagittal plane, x-y plane and trunk lateral flexion was defined as the movement in the frontal plane, y-z plane. The elbow excursion, which consisted of both elbow flexion and elbow extension, was calculated from the resulting angle between the shoulder, elbow and wrist markers. The shoulder excursion, separated in the

excursion of shoulder flexion/extension and the excursion of shoulder elevation/depression, was calculated from the resulting angle between the elbow and shoulder in respectively the x-z plane and the y-z plane.

Finally, several kinematic measures of walking were also calculated. Reaction time was determined as the difference between the moment that ball appeared from behind the curtain and the moment that participant's walking velocity increased beyond 0.05 m/s for 5 consecutive frames. The moment the ball appeared was registered by the timing gates placed just after the black curtain, whereas the timing gates placed at the starting position were used to constrain the search for the moment the participant first started walking (see Figure 1). Movement time was determined as the difference between the onset of walking and the moment of contact with the ball. The horizontal peak velocity was determined as the maximum velocity between the onset of walking and the time of contact. Deceleration time was represented by the time after peak velocity until the moment of contact. The walking velocity prior to contact (walk-VPTC) was calculated over the last 60 ms prior to contact [11], as well the average walking velocity, which was calculated by dividing the movement time by distance walked. Finally, we calculated the ratio between the peak velocity of walking and the maximum walking velocity measured prior to the experiment.

Statistics

Outcome performance was scored off-line by qualitative analysis of the video recordings. When a ball was intercepted at the right location (blue circle as described in the procedure and design section) it was scored as 1 and when the ball was missed it was scored as 0. Interceptions included trials in which a ball was successfully grasped or touched by the hand. Therefore, this classification system did not discriminate against grasp errors or fine position errors. These scores were transformed into percentages and the means were then submitted to repeated measures ANOVA.

For the linear and angular kinematics of the reach, the intra-participant mean was calculated for each condition, pooled across the group and then submitted to separate repeated measures ANOVA. The intra-participant mean provides a measure of the average performance across trials for each level of independent variable. The linear kinematic data of the wrist movement (i.e., TAPVX, TAPVY and PVX, PVY, and VPTC) were submitted to separate 2 Arm (impaired, non-impaired) \times 3 Ball Velocity (V1, V2, V3) \times 2 Frame of reference (world-centred, body-centred) ANOVA with repeated measures on

all factors. Data on initiation time of reach, movement time and angular excursion were submitted to separate 2 Arm (impaired, non-impaired) \times 3 Ball Velocity (V1, V2, V3) ANOVA with repeated measures on all factors. These variables are independent of the frame of reference calculation. For the dependent measures of walking, the intra-participant mean was calculated for each condition, pooled across the group and then submitted to separate 2 Arm (impaired, non-impaired) \times 3 Ball Velocity (V1, V2, V3) ANOVA with repeated measures on all factors. Again, these variables are independent of the frame of reference calculation.

Results

Outcome performance

Qualitative analysis revealed that for the balls with the lowest velocity (V1), participants intercepted 92% with the non-impaired arm and 91% with the impaired arm. (From the qualitative analysis of the videos, it was found that one participant was an outlier and was therefore excluded in both the qualitative as well as the quantitative analysis of this study). For the balls with the medium velocity (V2), they intercepted 79% with the non-impaired arm and 75% with the impaired arm. For the highest ball velocity (V3), they intercepted 66% with the non-impaired arm and 55% with the impaired arm (see Figure 2). ANOVA indicated no main effect of Arm ($F_{(1,9)} = 0.45$; $p > 0.05$), suggesting that a similar percentage of catches were made with the impaired arm and non-impaired arm. However, there a significant main effect of ball velocity ($F_{(2,18)} = 13.81$, $p < 0.01$), showing that less successful catches were made as ball velocity increased.

Linear kinematics of the reach (see Table II)

Initiation time of the reach. A significant main effect was noted for Ball Velocity ($F_{(2,16)} = 51.58$,

$p < 0.01$), and post hoc testing revealed that participants exhibited a significant reduction in initiation time for each successive increase in ball velocity ($p < 0.01$). There was no main effect of Arm ($F_{(1,8)} = 2.81$, $p > 0.05$).

Movement time and deceleration time. No significant main or interaction effects were found for the variable movement time. For deceleration time, there was a significant main effect of Frame ($F_{(1,8)} = 6.11$, $p < 0.05$), as well as a significant Frame \times Ball Velocity interaction ($F_{(2,16)} = 38.46$, $p < 0.01$). Post Hoc testing revealed that deceleration time was longer for V1 and V2 when measured in the world-centred compared to body-centred frame of reference. With the fastest ball velocity (V3), deceleration time of the wrist was shorter when analysed in a world-centred frame of reference compared to body-centred.

Peak velocity. For peak velocity in the x-dimension (PVX), main effects were found for Arm ($F_{(1,8)} = 11.07$, $p < 0.01$), Ball Velocity ($F_{(2,16)} = 32.95$,

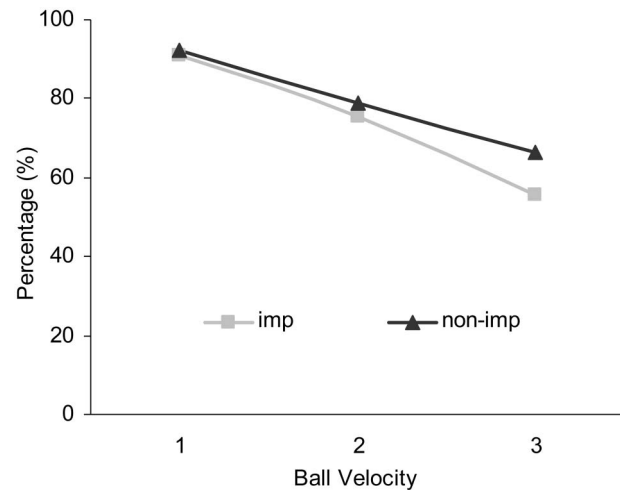


Figure 2. Percentage of successful interceptions as function of Arm (impaired—light grey line; non-impaired—black line) and ball approach velocity.

Table II. Mean (and SD) for the linear kinematics of the reach.

	Non-impaired			Impaired		
	V1	V2	V3	V1	V2	V3
Initiation (s)	1.37 (0.27)	0.83 (0.19)	0.54 (0.26)	1.26 (0.40)	0.78 (0.31)	0.35 (0.35)
MT (s)	0.79 (0.21)	0.73 (0.11)	0.76 (0.20)	0.85 (0.24)	0.82 (0.21)	0.93 (0.21)
DT-WC (s)	0.57 (0.17)	0.52 (0.14)	0.44 (0.12)	0.65 (0.20)	0.63 (0.21)	0.59 (0.15)
DT-BC (s)	0.46 (0.19)	0.47 (0.14)	0.57 (0.26)	0.53 (0.20)	0.53 (0.18)	0.62 (0.16)
PVX-WC (m/s)	1.04 (0.30)	1.75 (0.46)	2.15 (0.51)	0.90 (0.32)	1.52 (0.32)	1.85 (0.32)
PVX-BC (m/s)	0.55 (0.20)	0.84 (0.30)	0.97 (0.38)	0.37 (0.15)	0.58 (0.19)	0.66 (0.25)
PVY-WC (m/s)	0.51 (0.15)	0.57 (0.14)	0.49 (0.18)	0.57 (0.17)	0.59 (0.15)	0.54 (0.16)
PVYBC (m/s)	0.46 (0.11)	0.65 (0.13)	0.44 (0.12)	0.66 (0.21)	0.57 (0.18)	0.62 (0.22)
VPTCWC (m/s)	0.13 (0.15)	0.18 (0.17)	0.31 (0.18)	0.08 (0.09)	0.14 (0.10)	0.23 (0.12)
VPTCBC (m/s)	-0.01 (0.06)	-0.25 (0.14)	-0.47 (0.21)	-0.08 (0.1)	-0.28 (0.16)	-0.38 (0.19)

$p < 0.01$), and Frame ($F_{(1,8)} = 273.97$, $p < 0.01$). Post hoc testing indicated that participants exhibited a higher PVX when intercepting the ball with the fast (V3) compared to slow (V1) and medium velocity (V2), and that they achieved a lower PVX when reaching with the impaired arm irrespective of ball velocity. There was also a Ball Velocity \times Frame interaction ($F_{(2,16)} = 13.53$, $p < 0.01$), which was a result of a disproportionate increase in PVX as a function of ball velocity when calculated in the world-centred frame of reference. For the variable peak velocity in the y-dimension (PVY), no main effects were found for any of the factors. Significant interaction effects were found between Arm and Frame ($F_{(1,8)} = 8.32$, $p < 0.05$), and Ball Velocity and Frame ($F_{(2,16)} = 8.44$, $p < 0.05$), however post hoc analysis did not indicate any significant differences between relevant comparisons.

Velocity prior to contact. There was a main effect of Frame ($F_{(1,8)} = 70.00$, $p < 0.01$), as well as an interaction between Ball Velocity \times Frame interaction ($F_{(2,16)} = 47.79$, $p < 0.01$) and Arm \times Frame \times Ball Velocity ($F_{(2,16)} = 7.13$, $p < 0.01$). Participants exhibited a higher velocity prior to contact in world-centred coordinates when intercepting the fast compared to slow approaching ball. The opposite trend was observed when the velocity prior to contact was when calculated in body-centred coordinates, indicating that the wrist was moving backwards (i.e., negative velocity) relative to the trunk when arriving at the interception point.

Angular kinematics of the reach

For the variable elbow excursion, there was a main effect of Arm ($F_{(1,8)} = 4.35$, $p < 0.1$) and Ball Velocity ($F_{(2,16)} = 9.19$, $p < 0.01$). There was no interaction between Arm and Ball Velocity, thus indicating that although there was a reduced elbow excursion when reaching with the impaired arm, there was an increase in both arms when reaching for the faster approaching balls. This was confirmed by post hoc analysis, which showed an increase in elbow excursion when using the impaired or non-impaired

arms to intercept the fast compared to slow approaching ball ($p < 0.01$). For the variables shoulder elevation, shoulder flexion, trunk flexion and trunk rotation, main effects were found for Ball Velocity ($F_{(2,16)} = 17.97$, $p < 0.01$; $F_{(2,16)} = 19.27$, $p < 0.01$; $F_{(2,16)} = 8.62$, $p < 0.05$; and $F_{(2,16)} = 16.06$, $p < 0.01$, respectively). Participants exhibited more angular excursion of shoulder and trunk when the velocity of the ball increased. There was no main effect of Arm or interaction between Arm and Ball velocity, indicating that the increase in angular excursion was evident for both arms (see Table III). There was also a main effect of Arm for trunk lateral flexion ($F_{(1,8)} = 8.11$, $p < 0.05$), showing an increase of trunk lateral flexion when reaching with the impaired arm.

Linear kinematics of walking (see Table IV)

Reaction time of walking. No significant main effects were found for either Arm or Ball Velocity ($F_{(1,8)} = 0.23$, $p > 0.05$ and $F_{(2,16)} = 1.99$, $p > 0.05$, respectively). There was also no significant interaction effect.

Movement time of walking. A significant main effect of Ball Velocity was noted for movement time ($F_{(2,16)} = 21.99$, $p < 0.01$). Post hoc analysis revealed a significant difference between movement time for all ball velocities ($p < 0.01$); participants reduced their time spent walking when the ball velocity was increased.

Deceleration time of walking. For deceleration time there was a significant main effect for Ball Velocity ($F_{(2,16)} = 67.52$, $p < 0.01$). Post hoc testing revealed a significant difference in deceleration time of walking between all ball approach velocities ($p < 0.01$); participants reduced the time spent decelerating towards the interception when ball velocity increased. The main effect of Arm approached conventional levels of significance ($F_{(1,8)} = 4.1$, $p = 0.07$), which indicates a trend across ball velocities for the deceleration time of walking to be lengthened when using the impaired

Table III. Mean (and SD) for the angular kinematics of the reach.

	Non-impaired			Impaired		
	V1	V2	V3	V1	V2	V3
Elbow excursion (°)	53.46 (23.67)	57.81 (22.59)	65.63 (21.05)	33.31 (13.21)	44.41 (17.34)	55.72 (24.01)
Shoulder elevation (°)	12.26 (7.08)	18.41 (7.86)	21.73 (9.88)	14.21 (9.63)	20.18 (12.19)	22.97 (5.95)
Shoulder flexion (°)	35.32 (14.45)	52.15 (31.72)	63.50 (30.33)	33.48 (18.06)	50.32 (17.54)	60.47 (17.54)
Trunk flexion (°)	27.88 (11.13)	46.23 (17.70)	52.41 (23.71)	40.24 (20.95)	47.41 (20.33)	59.28 (18.55)
Trunk rotation (°)	22.93 (8.10)	31.14 (11.97)	36.37 (10.93)	22.26 (6.79)	30.71 (8.93)	41.53 (14.05)
Trunk lateral flexion (°)	20.36 (12.63)	23.06 (9.46)	30.49 (23.20)	31.88 (17.61)	37.18 (19.29)	56.91 (40.05)

Table IV. Mean (and SD) of linear kinematics of walking.

	Non-impaired			Impaired		
	V1	V2	V3	V1	V2	V3
Reaction time (s)	0.70 (0.27)	0.63 (0.18)	0.57 (0.19)	0.72 (0.30)	0.59 (0.13)	0.60 (0.17)
Movement time (s)	2.11 (0.23)	1.53 (0.18)	1.31 (0.32)	2.22 (0.29)	1.58 (0.17)	1.27 (0.21)
Deceleration time (s)	1.35 (0.24)	0.77 (0.15)	0.43 (0.12)	1.56 (0.35)	0.85 (0.17)	0.53 (0.18)
Peak velocity (m/s)	1.10 (0.26)	1.23 (0.20)	1.53 (0.29)	1.11 (0.23)	1.23 (0.20)	1.47 (0.25)
Wlk-VPTC	0.16 (0.06)	0.50 (0.28)	0.79 (0.26)	0.19 (0.13)	0.52 (0.20)	0.73 (0.17)
Average velocity	0.62 (0.05)	0.86 (0.14)	1.06 (0.26)	0.59 (0.07)	0.84 (0.13)	1.05 (0.17)

arm compared to non-impaired arm (959 ms and 883 ms, respectively).

Peak velocity of walking. For peak velocity of walking there was a significant main effect for Ball Velocity ($F_{(2,16)} = 18.21$, $p < 0.01$). Post hoc analysis revealed a significant difference between ball velocity 1 and 3 ($p < 0.01$), and ball velocity 2 and 3 ($p < 0.01$); participants exhibited a higher peak velocity of walking when intercepting the ball with the highest velocity. There was no difference between velocity 1 and 2.

Walking velocity prior to contact. A main effect was found for Ball Velocity ($F_{(2,16)} = 40.09$, $p < 0.01$). Post hoc testing showed significant differences between all ball velocities ($p < 0.01$), with participants increasing their walking velocity prior to contact as ball velocity increased.

Average walking velocity. A main effect was noted for the Ball Velocity ($F_{(2,16)} = 16.02$, $p < 0.01$); participants increased their average walking velocity when intercepting the ball with the highest velocity. Additionally, when examining the ratio between the peak walking velocity and the maximum walking velocity measured prior to the experiment, a main effect for Ball Velocity was noted ($F_{(2,16)} = 11.99$, $p < 0.01$). Single-sample t-tests showed that the walking velocity exhibited when intercepting ball velocity 1 and 2 was similar to the maximum walking velocity determined prior to experiment (the ratio was close to an hypothesized unity ratio). However, this was not the case when intercepting ball velocity 3; the ratio was significantly higher ($p < 0.05$) than unity indicating that participants exceeded their pre-determined maximum walking velocity when walking to intercept the fastest approaching ball (see Figure 3).

Discussion

In the present study it was examined whether children with SHCP adapt the coordination of their walking and reaching movements when intercepting

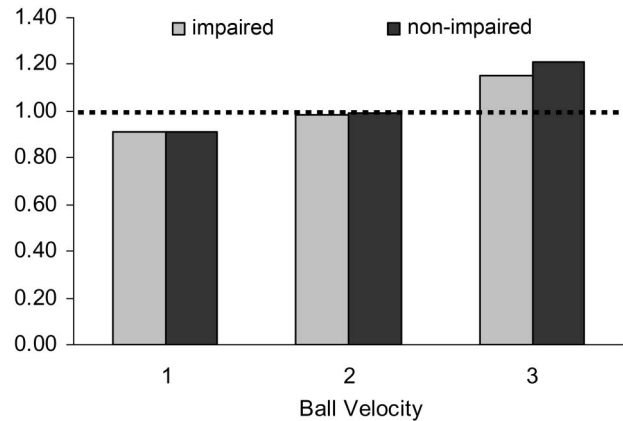


Figure 3. Ratio of peak velocity of walking exhibited in each condition to maximum walking velocity measured prior to experimentation.

balls with different approach velocities, and furthermore how they compensate for their impairment. Several modifications to the kinematic measures were found, indicating that a complex series of adaptations to the walking and reaching movements occurred when the ball approach velocity was increased. First, with increasing ball approach velocity there was an increase in peak velocity of walking and walking velocity prior to contact, and a decrease in movement time and deceleration time of walking. Because there was no modification to reaction time, these changes to walking behaviour were required in order to compensate for the change in time-to-arrival as ball velocity increased. The effect of ball approach velocity was also reflected in the reaching kinematics, where there was a later initiation time, higher wrist peak velocity, higher wrist velocity prior to contact, and more angular excursion when intercepting the fast approaching ball. The increased wrist peak velocity during the reach and prior to contact compensated for the later initiation time of reaching (i.e., closer to moment of interception), and contributed to more elbow excursion being made in a similar movement time. Second, although there were differences between the impaired and non-impaired arms in the amount of elbow and trunk excursion, as well the peak wrist

velocity, the effects of ball velocity were evident irrespective of which arm was used. Finally, the changes in movement kinematics as a result of ball velocity were evident in the outcome scores, although these were the same for the impaired and non-impaired arms. The implication is that SHCP children made specific adaptations to their walking and reaching kinematics to the different ball approach velocities, but still these were not sufficient to maintain outcome performance.

The coupling of movement to object velocity has been consistently reported in many different interceptive actions in participants without movement disorders [14–18]. The current study indicates that velocity coupling also exists in children with SHCP participants, irrespective of whether they intercept with their impaired or non-impaired arm. However, this finding is not entirely in accord with previous work [10], which reported that children with SHCP compensated for their impairment by initiating the hitting action earlier with the impaired arm compared to the non-impaired arm. The question therefore remains how can these seemingly discrepant findings be explained? A likely possibility could be that the hitting task required a different perception-action coupling than a reaching and grasping task. For instance, it has been suggested that although timing is very important in both catching and hitting tasks, the perception-action coupling for ball catching should result in a soft contact between the hand and ball, whereas hitting requires a contact that should rebound the ball with a much faster velocity [4]. This means that in hitting tasks the participant typically attempts to maximize hand/implementation velocity at contact with the ball. However, the ability to move the arm with high speeds is restricted by SHCP, and often participants avoid making fast movements. The SHCP children who performed the hitting task adapted their initiation time to compensate for the restricted movement capabilities of the impaired arm. In the present study, although the interception task did not necessitate maximum velocity at contact, there was a quite severe externally-imposed timing constraint that increased as a function of ball approach velocity. It appears that in order to satisfy the external timing constraint, while maintaining the necessary soft contact between the ball and hand, SHCP children did not find it necessary to modify the timing of their reach movement when using the impaired arm.

Although few differences were found between the impaired and non-impaired arm in the timing of the walking and reaching movements, we did find evidence of modified movement of the impaired arm in the variables, peak velocity, elbow excursion and trunk lateral flexion. Similar changes to movement were also found in previous research on interceptive

actions in adults and children with SHCP [2,7,19]. We suggest that the increased contribution from the trunk compensated for the reduction in elbow excursion and wrist peak velocity. In combination, these changes enabled a reduced movement of the arm to be performed slower but with a similar movement time.

It is noteworthy however, that although there was a difference between the impaired and non-impaired arms, there was an increased elbow excursion and peak velocity in both arms as a function of ball approach velocity. This finding is consistent with other rehabilitation research, which showed that movement of the impaired limb can be facilitated by providing patients with externally-paced tasks, and in fact can improve such that it approaches performance of the non-impaired limb [20–23]. A similar finding was evident in the walking kinematics, where it was found that Children with SHCP adapted their walking velocity in response to the different ball approach velocities. The important point to note is that the walking velocity exhibited when intercepting the ball with fastest approach velocity was greater than their apparent maximum. This indicates that the walking velocity measured prior to the experiment was in fact not their maximum, and that the addition of an external timing constraint facilitated the production of a faster walking velocity. The implication is that the inclusion of a functional task goal (move from A to B to intercept an object) enabled children with SHCP to walk faster than when given an arbitrary verbal instruction [13,21,24].

Practical implications

From the present findings there are several practical implications for rehabilitation of children with SHCP. One important consideration is that therapy should not only focus on “treating” the impaired motor apparatus, but should also encourage children with SHCP to couple perception and action, and thus practice within their own functional movement possibilities. Rehabilitation should place children with SHCP in situations where they have to discover, accommodate and exploit the internal and external constraints so that they can then adapt flexibly to the changing conditions they encounter when interacting within the surrounding environment [25]. Another important issue that arises from the present findings is that a severe external time constraint can facilitate movements of the impaired arm in a similar way to the non-impaired arm. The implication is that in order to evoke adaptive limb movements, rehabilitation should consider challenging patients with severe external timing constraints rather than only emphasizing tasks that allow them to generate the pace

of their movement (internal timing). In doing so, it is also essential for therapy to recognize the importance of using tasks that have behaviourally relevant goals. It remains an exciting research topic to determine whether rehabilitation that encourages and challenges children with SHCP to discover and exploit their own action capabilities will have lasting effects.

References

1. Utley A, Sugden D. Interlimb coupling in children with hemiplegic cerebral palsy during reaching and grasping at speed. *Develop Med Child Neurol* 1998;40:396–404.
2. Ricken AXC, Bennett SJ, Savelsbergh GJP. Coordination of reaching in children with Spastic Hemiparetic Cerebral Palsy under different task demands. *Motor Control Special Issue*; 2005;9(4):357–371.
3. Van der Kamp J, Savelsbergh GJP, Smeets JBJ. Multiple information sources in interceptive timing. *Human Movement Sci* 1997;16:787–821.
4. Caljouw SR, Van der Kamp J, Savelsbergh GJP. Timing of goal-directed hitting: Impact requirements change the information-movement coupling. *Experim Brain Res* 2004;155:135–144.
5. Warren WH. Perceiving affordances: Visual guidance of stair climbing. *J Experim Psychol: Human Percept Performance* 1984;13:371–383.
6. Konczak J, Meeuwse HJ, Cress ME. Changing affordances in stair climbing: The perception of maximum climbability in young and older adults. *J Experim Psychol: Human Percept Performance* 1992;18:691–697.
7. Steenbergen B, Hulstijn W, Lemmens IHL, Meulenbroek RGJ. The coordination of reaching and grasping in spastic hemiparesis. *Human Movement Sci* 2000;19:75–105.
8. Van Roon D, Steenbergen B, Meulenbroek RGJ. Trunk recruitment during spoon use in tetraparetic cerebral palsy. *Experim Brain Res* 2004;155:186–195.
9. Van Thiel E, Meulenbroek RGJ, Hulstijn W, Steenbergen B. Kinematics of fast hemiparetic aiming movements towards stationary and moving targets. *Experim Brain Res* 2000;132(2):230–242.
10. Van der Meer ALH, Van der Weel FR, Lee DN. Measuring dysfunction of basic movement control in cerebral palsy. *Human Movement Sci* 1996;15:253–283.
11. Ricken AXC, Savelsbergh GJP, Bennett SJ. Coordinating degrees of freedom during interceptive actions in children. *Experim Brain Res* 2004;156:415–421.
12. Lough S, Wing AM, Fraser C, Jenner JR. Measurement of recovery of function in the hemiparetic upper limb following stroke: A preliminary report. *Human Movement Sci* 1984;3:247–256.
13. Volman MJM, Wijnroks A, Vermeer A. Effect of task context on reaching performance in children with spastic hemiparesis. *Clinical Rehabil* 2002;16:684–692.
14. Smeets JBJ, Brenner E. Perception and action are based on the same visual information-distinction between position and velocity. *J Experim Psychol: Human Percept Performance* 1995;21:19–31.
15. Carnahan H, McFadyen BJ. Visuomotor control when reaching toward and grasping moving targets. *Acta Psychologica* 1996;92:17–32.
16. Bennett SJ, Van der Kamp J, Savelsbergh GJP, Davids K. Timing a one-handed catch I. Effects of telestereoscopic viewing. *Experim Brain Res* 1999;129:362–368.
17. Brouwer AM, Brenner E, Smeets JBJ. Hitting moving objects: the dependency of hand velocity on the speed of the target. *Experim Brain Res* 2000;133:242–248.
18. Tresilian JR, Oliver J, Carroll TJ. Temporal precision of interceptive action: Differential effects of target size and speed. *Experim Brain Res* 2003;142:193–207.
19. Van Thiel E, Steenbergen B. Shoulder and hand displacements during hitting, reaching, and grasping movements in hemiparetic cerebral palsy. *Motor Control* 2001;2:166–182.
20. Lough S. Visuo-motor control following stroke: A motor skills perspective. Unpublished doctoral dissertation: Edinburgh University, Edinburgh, Scotland; 1985.
21. Majsak MJ, Kaminski T, Gentile AM, Flanagan JR. The reaching movements of patients with Parkinson's disease under self-determined maximal speed and visually cued conditions. *Brain* 1998;121:755–766.
22. Trombly C, Wu CY. Effect of rehabilitation tasks on organization of movement post stroke. *Am J Occupat Ther* 1999;53:333–444.
23. Wu C, Trombly C, Lin K, Tickle-Degnen L. A kinematic study of contextual effects on reaching performance in persons with and without stroke: influences of object availability. *Arch Phys Med Rehabil* 2000;81:95–101.
24. Van der Weel FR, Van der Meer ALH. Effect of task on movement control in cerebral palsy: Implications for assessment and therapy. *Develop Med Child Neurol* 1991;33:419–426.
25. Savelsbergh GJP, Van der Kamp J. Information in learning to co-ordinate and control movements: Is there a need for specificity of practice? *Int J Sport Psychol* 2000;31:1–18.